MAURI ORA, 1979, 7: 117-137

DYNAMICS AND CONDITION OF OPOSSUM (*TRICHOSURUS VULPECULA* KERR) POPULATIONS IN THE COPLAND VALLEY, WESTLAND, NEW ZEALAND

K.W. FRASER

Department of Zoology, University of Canterbury, Christchurch, New Zealand

ABSTRACT

Aspects of the population dynamics and condition of one hundred and eighty-one opossums in areas with differing densities in the Copland Valley, Westland National Park, were investigated in January and February 1978. Autopsies of poisoned opossums provided information on population dynamics, condition and growth. Poisoning success results gave an indication of the relative densities of populations in the lower (10.11% poisoning success), mid- (6.94%), and upper (3.04%) Copland Valley. The high density population from the lower Copland Valley had a predominance of individuals in the adult age classes (3+ years and above, 69.7%) whereas the moderate density population from the mid-Copland Valley had a predominance of individuals in the younger age classes (1+ and 2+, 56%; cf. 13.5% for the high density population). The sample from the low density population in the upper Copland Valley was too small (n=17) for conclusive analysis although its characteristics were, in general, similar to those of the population in the mid-Copland Valley. The high density population had a significant excess of females (57♀♀:32♂♂) and the moderate density population had a significant excess of males (27♀♀:46♂♂). Females became sexually mature younger in the low and moderate density populations than in the high density population but males matured at similar ages in the three populations. When all the data were pooled there was a significant excess of males in the 0+ age class (5♀♀:19♂♂). Females predominated in the adult age classes with the 4+ age class having a significant excess of females (20♀♀:5♂♂). Mean adult body weights for opossums in the moderate density area (3.58 $\pm$ 0.67 kg) were significantly greater than those in the high density area (3.27 $\pm$ 0.57 kg), and males (3.46 $\pm$ 0.54 kg) were significantly heavier than females (2.99 $\pm$ 0.85 kg) in the high density population only. Condition, as indicated by abdominal fat deposits, varied significantly between the high and moderate density populations. Mean kidney weight showed a similar relationship and growth of the kidneys was negatively heterogonic. Other indices of condition, such as signs of fighting and the incidence of parasites, verified that opossums from the high density population in the lower Copland Valley were in poorer condition.

INTRODUCTION

The Australian brush-tailed opossum *(Trichosurus vulpecula* Kerr [Marsupialia: Phalangeridae]) was introduced into New Zealand about 1840 (Pracy 1962) and liberations continued until 1924. Accounts of the distribution and spread of opossums in New Zealand are given by Wodzicki (1950) and Pracy (1962).

The opossum is now considered the main problem mammal in New Zealand (Holloway 1973), because of destruction caused in indigenous protection forests (Wodzicki 1950, Holloway 1959, 1970), exotic production forests (Farmer 1973), on pastoral land (Harvie 1973), and wherever soil stabilisation using poplars or willows is undertaken (Holloway 1973). Also they are carriers of bovine tuberculosis (*Mycobacterium tuberculosis*) and can re-infect cattle with this disease (Miers 1973).

This project investigates physical aspects of the population dynamics and condition of opossums in areas with different population densities. Caughley (1967, 1969) found that ungulate populations at different stages of eruptive fluctuations have different population dynamics features which are a consequence of their history. The condition of individual animals gives an indication of their physical well-being, total fat reserves, breeding potential, and the incidence of disease and parasites. A measure of the condition of many individuals can therefore yield valuable information on the population and its relationships with the habitat. The general theme of this research was, therefore, to ascertain the nature of such population dynamics and condition features for a series of opossum populations in the Copland Valley believed to represent various stages of eruptive fluctuations.

STUDY AREA

This work was carried out in the Copland Valley at the southern end of Westland National Park (Fig. 1). The study area is deeply-dissected upland separated from coastal terraces and farmland by the Alpine Fault. To the east of the fault line there are high ridges and deep, steep-sided slopes, particularly towards the heads of the valleys. The frontal hills are less steep with rounded, ice-worn tops. Skeletal forest soils on the steep land are generally shallow, infertile and consist mainly of freshly weathered soil, disintegrating rock fragments from the parent schists, and some decomposing plant remains (New Zealand Soil Bureau 1950, 1968). The valley floor is characterised by terrace soils of the yellow-brown earth variety.

The area lies within the zone of prevailing westerly winds from the Tasman Sea which cause heavy precipitation and mist when they are forced to rise over the mountain ranges. Precipitation is heavy throughout the year but tends to be greatest in spring and summer. In winter much of the precipitation at higher altitudes falls as snow. The mean annual precipitation in the area (Franz Josef Glacier, 1926-69) is 4980 mm (New Zealand Meteorological Service 1973).

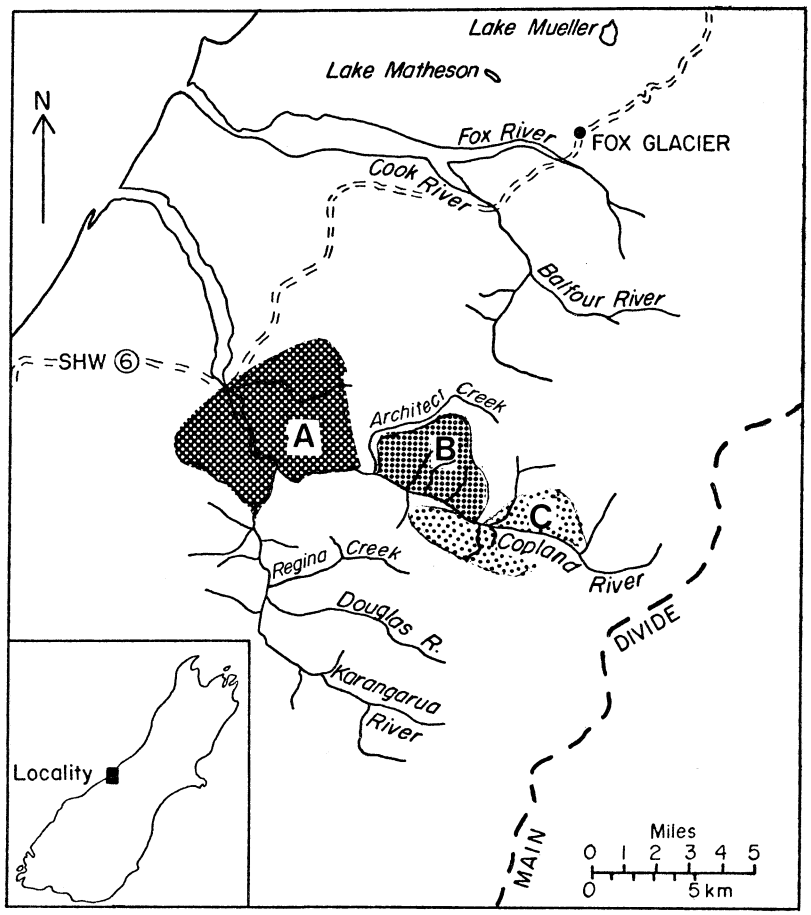

Fig. 1 Location of the Copland Valley (43°38'S, 169°45'E) in south Westland and the extent of the three study areas (relative opossum density H = high, M = moderate, L = low).

The forest of the Copland Valley is mainly a mixed hardwood association, usually with a closed canopy, but there is a gradual transition in the composition of the plant associations with both altitude and distance up the valley. The major factors influencing these changes are soil type and slope.

Control of opossum numbers now presents a major conservation problem as they are responsible for the destruction of southern rata (*Metrosideros umbellata*), kamahi (*Weinmannia racemosa*), Hall's totara (*Podocarpus hallii*), five-finger (*Pseudopanax colensoi*), fuchsia (*Fuchsia excorticata*) and several other plant species (Wardle 1977). These species are particularly important components of the plant communities in Westland National Park, especially with respect to the habitat requirements of many native bird species.

A more complete description of the vegetation and damage by opossums is given by Fraser (1978).

Other introduced mammals present in Westland National Park include red deer (*Cervus elaphus*), chamois (*Rupicapra rupicapra*), thar (*Hemitragus jemlahicus*), goats (*Capra hircus*), and stoats (*Mustela erminea*).

METHODS

Opossums were sampled in the three areas of different density by poisoning during January and February 1978. The baits consisted of sodium cyanide paste flavoured with a covering of flour and an aromatic lure of raspberry. Ten poison lines were established in the three study areas, usually from the valley floor up the valley sides. Usually lines followed ridges where the vegetation was more negotiable and more opossum sign was evident. The baits, applied at approximately 20 m intervals to the bases of trees or logs, were examined after one or two nights of fine weather.

Field autopsy of all specimens recorded sex; neck, rump and tail-tip colour; total and tail length to the nearest 5 mm; body weight to the nearest 10 g and the dental formula. The second and third mandibular molars were removed for ageing. A subjective estimate of condition was made by feeling along the back and rump and recorded on a scale of 1-3. The presence of ectoparasites and any external signs of disease were recorded. The kidneys were removed, stripped of fat and weighed to the nearest 0.1 g. The visceral fat deposits were scored on a rating similar to that used by Riney (1955). The scale for scoring the animal's fat reserves was as follows:

1 - no trace of fat in any region or very small amounts of fat present;

2 - moderate amounts of fat present (intermediate in quantity between 1 and 3);

3 - fat abundant in all the regions examined.

For males, the state of the prostate gland was recorded and for females, an assessment of sexual maturity based on the development of the pouch and teats was made. If the pouch was absent or the teats were invaginated the female was classed as immature. Females with well-developed, deep pouches and evaginated teats were classed as sexually mature.

Ageing was by counting molar cementum annuli following mounting, etching, and staining methods described by Pekelharing (1970). The translucent layers were counted and the animals grouped according to the number of full years they had completed (e.g. 30 month animals were classed as 2+ years).

RESULTS AND DISCUSSION

POPULATION DYNAMICS

Population dynamics give an indication of the status of the population and this can ultimately be related to the condition of the individuals (e.g. increasing populations usually have individuals in good condition). Essentially, a population is either increasing, static, or declining depending upon whether it has a positive, zero, or negative rate of increase. The rate of increase is the sum of the effects of all the population processes and knowledge of this is immensely valuable in animal control and management.

Estimates of the rates of increase of introduced mammal populations can be made only by observing the populations over time (Caughley and Birch 1971). Although estimates of rates of increase were impossible in this study, analyses of age structures, sex ratios, and ages at maturity indicate the status and trends of the opossum populations.

One hundred and eighty-one opossums were poisoned in the three study areas. The poisoning success data in Table 1 give an indication of the relative population densities of the areas and support the suggested dispersal pattern (Fraser 1978).

TABLE 1. POISONING SUCCESS IN AREAS OF DIFFERENT POPULATION DENSITY, COPLAND VALLEY, 1978. *

Area	No. baits	No. opossums killed	Poisoning success (%)
High	880	89	10.11
Moderate	1051	73	6.94
Low	460	14	3.04

* Pouch young not included

Age structure

Age structure for each of the three populations of different density are shown in Fig. 2. Clearly, the high and moderate density populations have different age structures. The high density population has a predominance of adults (2+ and above, 76.4%) with fewer juveniles (0+, 16.9%) and sub-adults (1+, 6.7%). The population has a mean age of 3.8 years. This age structure indicates a low rate of recruitment, characteristic of a stable or declining population.

The age structure of the moderate density population is typical of an increasing population. There is a preponderance of individuals in the younger post-juvenile age classes. Opossums in the 1+ and 2+ age classes constitute 56.0% of the population, compared to 13.5% for the high density population. The mean age for this population is 2.4 years, considerably less than the high density population.

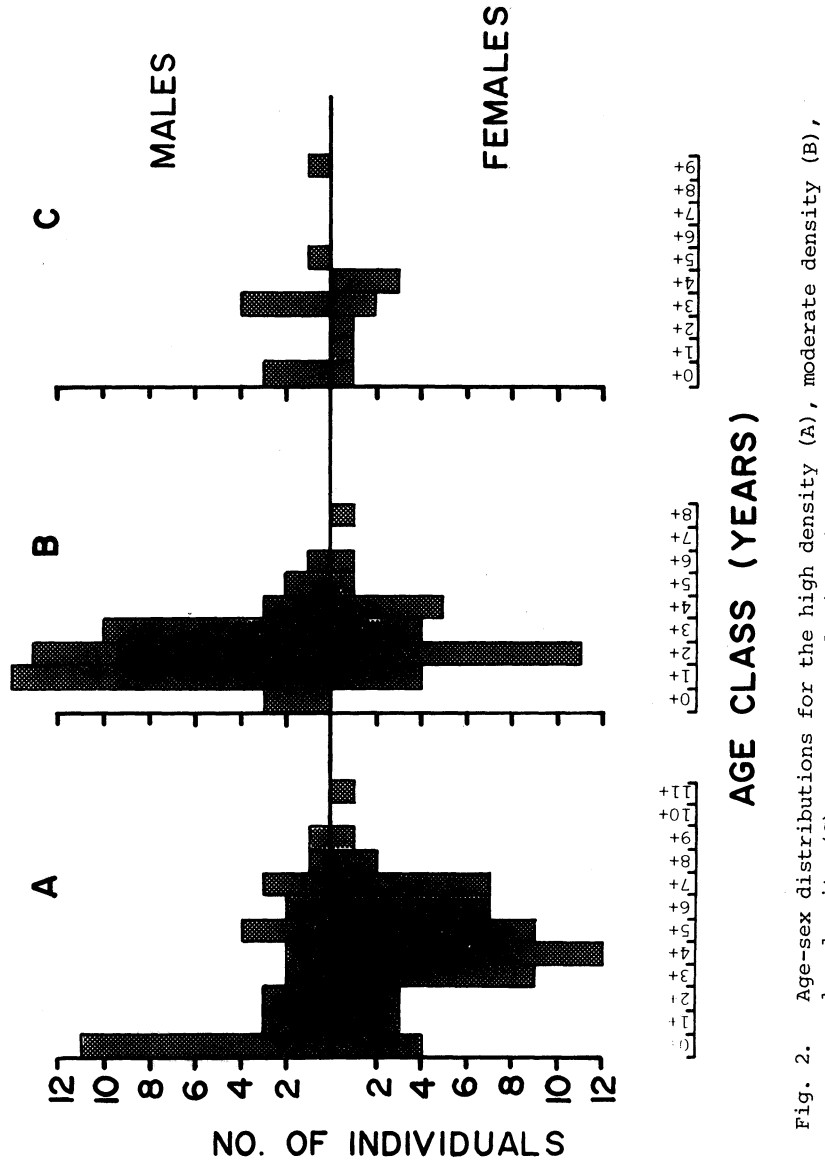

Fig. 2. Age-sex distributions for the high density (A), moderate density (B), low density (C) opossum populations in the Copland Valley.

The small sample size for the low density population precludes any definite conclusions about its age structure although it is probably similar to that of the moderate density population. The mean age of the low density population is 2.8 years.

Most of New Zealand's opossum populations are continually poisoned, shot, or trapped and these artificial mortality factors keep the populations from reaching a long-term balance with their habitat. The high density population is no

exception since, being easily accessible, it has been trapped each winter for several years. This regular removal of individuals may prevent it from attaining a stationary age distribution (i.e. constant population size and birth rate equal to the death rate).

Previous work on Bennett's wallaby (*Macropus rugogriseus fructicus*) (Catt 1975) and opossums (Warburton 1977) indicates that artificial mortality factors can be important and do influence a population's age distribution. Both studies found that artificial mortality contributed a large proportion of the total mortality and that it was not age specific. Therefore, the regular removal of individuals from the population each year creates better opportunities for juveniles to find suitable home ranges, and adequate food and shelter for survival. Such a non-selective mortality factor is more significant in a high density population where resources are at a premium. This could explain the abnormally large number of juveniles for a population near peak density.

A major anomaly in the age distribution of the moderate density population is the lack of juveniles (only 4.0% of individuals). Normally in an expanding population, juveniles form a large proportion of the population. The number of individuals in the 0+ age class taken in the high density area implies that there is no sampling bias with respect to age. The scarcity of juveniles in the moderate density area could be due to dispersal of individuals recently independent of their mothers. The majority of animals were taken between Architect Creek and Welcome Flat where the highest density of opossums in the moderate density area occurred (Fraser 1978). Dispersal of newly independent young would be away from this area.

Further, although family groups (mother and young) were often killed by a single bait in the high density area, this did not occur in the moderate and low density areas, except where the young were from Spring births. I suspect that in these two areas young became independent of their mothers at an earlier age through better nutrition and faster growth.

Errors in the ageing technique are most significant in the younger age classes where teeth annuli frequently are not well-developed and the first opaque layer is difficult to identify. Physical parameters (length, weight) provided a check of age especially in the high density population. Juveniles in the moderate density population however, were larger and in better condition and there was correspondingly less distinction between them and older animals. Physical and botanical characteristics are reasonably homogeneous over the three areas and are unlikely to have contributed to the differences in opossum density or demography.

Sex ratios

Sex ratios are often correlated with mating behaviour (Kendeigh 1961) and can therefore affect the reproduction potential of a population. The sex ratios differ markedly between the high and moderate density populations. In the high

density population there was a significant excess of females (57♀♀:32♂♂; X^2=7.02, p<.01, n=89) whereas in the moderate density population there was a significant excess of males (27♀♀:46♂♂; X^2=4.94, p<.05, n=73).

Two factors could influence sex ratios. Male opossums, especially young ones, are more mobile than females (Tyndale-Biscoe 1955, Dunnet 1956, 1964, Crawley 1973) and this could lead to more males being poisoned. The high density area has been trapped for a number of years but only recently has there been trapping in the moderate density area. The possible removal of more males from the high density area may lead to an abundance of females. In the moderate density area however trapping pressure has probably been insufficient to cause any significant deviations from a sex ratio close to parity. Males, with their greater mobility, probably encounter more baits than females resulting in the moderate density sample containing excess males.

More likely however is a differential life expectancy between the sexes. When data for all three areas are pooled a definite trend in the overall age distribution is evident (Table 2). The 0+ age class contains a significant excess of males (5♀♀:19♂♂; X^2=8.16, p<.01, n=24) but there is a gradual trend for predominance of males in the juvenile and sub-adult cohorts giving way to a greater number of females in the older age classes. The 4+ age class contains a significant excess of females (20♀♀:5♂♂; X^2=9.00, p<.01, n=25) and, although the ratios are not statistically significant in other adult cohorts, a trend in favour of females is evident.

TABLE 2. SEX RATIOS FOR EACH AGE CLASS OF OPOSSUMS IN THE COPLAND VALLEY, 1978.

Age class	Males	Females	Per cent males	X^2	Level of Significance
0+	19	5	79.2	8.16	.01
1+	17	9	65.4	2.46	n.s.
2+	16	17	48.5	0.03	n.s.
3+	16	15	51.6	0.03	n.s.
4+	5	20	20.0	9.00	.01
5+	7	10	41.2	0.53	n.s.
6+	3	8	27.3	2.27	n.s.
7+	3	7	30.0	1.60	n.s.
8+	1	3	25.0	1.00	n.s.
9+	2	1	66.7	0.33	n.s.
10+	-	-	-	-	-
11+	-	1	-	-	-

Sex ratios favouring males in the juvenile and sub-adult cohorts have been found in a number of other opossum populations (Voller 1969, Boersma 1974, Coleman 1976, Warburton 1977). Bamford (1972) recorded a sex ratio at parity amongst adults following a disparate ratio amongst sub-adults in favour of males.

Although sex ratios favouring males are well-known for eutherian mammals (Parkes 1926), there is no conclusive evidence for this in marsupials. Caughley and Kean (1964) found the sex ratio of 908 opossum pouch young to be significantly in favour of males. This trend is evident in many opossum populations, both in New Zealand and Australia (Dunnet 1964, Boersma 1974, J.D. Coleman, F.R.I. pers. comm.). Although figures from the Copland Valley are for the 0+ age class, only 5 of the 24 individuals sampled were pouch young. The rest were the result of the previous year's breeding season and were approximately 9-10 months old. Consequently the observed ratio in Table 2 may also reflect post-natal mortality effects.

Breeding

The major breeding season is during March-June with an occasional minor peak in August-November when considerably fewer females breed (Kean and Pracy 1949, Tyndale-Biscoe 1955, Dunnet 1964). Most adult females rear one young per year, but some females rear two, one in each season (Kean 1971). Age at first breeding varies between populations (Crawley 1973) and is probably dependent primarily on density and related habitat requirements.

Ideally, fecundity should be examined during the main breeding season with the criterion for a fecund female being the presence or evidence (i.e. lactation) of pouch young. Since these populations were not sampled during the breeding season, female sexual maturity, implying ability to breed, was used to estimate fecundity. This was based on the condition of the pouch and teats.

This assessment of maturity for 1+, 2+ and 3+ age classes in the moderate and high density populations is shown in Table 3. The low density population sample is too small to analyse. In the high density area none of the females was sexually mature in the 1+ or 2+ age classes but all except two of the animals in the 3+ age class were mature. In the moderate density area, however, more than 50% of the females in the 2+ age class were sexually mature. These estimates of age specific maturity support the hypothesis of different reproductive potentials in high and moderate density populations.

TABLE 3. AGE AT SEXUAL MATURITY FOR YOUNG FEMALE OPOSSUMS IN THE HIGH AND MODERATE DENSITY POPULATIONS, COPLAND VALLEY, 1978.

Age class	N	No. mature	No. immature
High density:			
0+	3	-	3
2+	3	-	3
3+	9	7	2
Moderate density:			
1+	4	-	4
2+	13	7	6
3+	4	4	-

Twenty-nine adult females were taken from the moderate density population of which two had Spring births compared with no Spring births by 51 females from the high density population. In the low density area three of the six females taken had Spring births.

Bamford (1972) examined the fecundity of populations at various stages of an eruptive fluctuation and found a decline in fecundity in the youngest and oldest age classes in a stabilising population. Thus changes in fecundity, particularly in young females, are at least partly responsible for changes in the rate of increase. The difference in age at sexual maturity between areas implies that physiological development of the reproductive organs in young females may be slowed by high population density. Kean (1967) suggested that inhibition of breeding in older females may result from social behaviour.

Spring breeding is considered supplementary (Kean 1971) and most likely to occur at low population densities and when food is plentiful. Kean (1971) suggested that double breeders are present in all populations but that this device for higher reproductive rate is favoured only in expanding populations, when densities are low and food supplies plentiful.

Development of the prostate gland was taken as the index of male sexual maturity. The marsupial prostate gland is considered homologous to the separate accessory sex glands of other mammals (Gilmore 1966). In an immature opossum the prostate is very small and usually weighs less than one gram but with the onset of maturity it rapidly increases in size (Gilmore 1966). Seasonal variation in the size and weight of the prostate in mature males is characterised by a marked increase in both these parameters just prior to the main breeding season (Gilmore 1966). As the Copland Valley populations were sampled in this period sexually mature and immature males were readily distinguished.

In both the high and moderate density populations the same pattern of prostate development is evident (Table 4). More than 50% of the males in the 2+ age class were sexually mature and all the males in the 3+ age class were sexually mature. Surprisingly, the onset of sexual maturity in males seems unaffected by population density.

TABLE 4. MATURITY OF MALE OPOSSUMS AS INDICATED BY THE STATE OF DEVELOPMENT OF THE PROSTATE GLAND FOR THE HIGH AND MODERATE DENSITY POPULATIONS, COPLAND VALLEY, 1978.

Age class	N	Developed	Undeveloped
High density:			
1+	3	-	3
2+	3	2	1
3+	2	2	-
Moderate density:			
1+	14	-	14
2+	13	9	4
3+	10	10	-

Cole (1954) and Caughley & Birch (1971) showed the relationship of age structures of populations to their rates of increase and to longevity. On this basis the age structures for the high and moderate density populations indicate that the former is almost static while the latter is increasing. The low density population is probably increasing also. Sex ratio results indicate a greater life expectancy of female opossums following a disparate sex ratio in juvenile and sub-adult cohorts in favour of males. The consequent effects on the age structures of the high and moderate density populations enhance the sex ratio differences. Female longevity has little effect on an expanding population with a relatively young mean age, while a preponderance of males in the young age classes will have a considerable effect on the overall sex ratio. These effects are reversed in the high density population with its predominance of adults and a higher mean age. The difference in age at female sexual maturity between the high and moderate density populations and the occurrence of Spring births in the moderate and low density populations only implies a density effect on the population reproductive rate. That three of six mature females from the low density population had Spring births, an unusually high ratio, implies that double breeding may occur in this pioneer population.

GROWTH AND CONDITION

Analysis of growth and condition provides information on the state of individuals within the population and reflects conditions conducive to growth over a number of years. Brody (1945), Von Bertalanffy (1934), and others have developed growth equations that utilise measurements of body size based upon the assumption that animals grow towards an ultimate or asymptotic body size. The growth rate given by such equations is useful for the comparison of growth in different populations. Further, size and fat reserves are good indices for examining populations with different levels of food resources.

Total fat reserves (often referred to as condition) are an indication of general nutrition in most mammal populations while physical fitness, the incidence of disease, and parasites all contribute to condition. Fat however is a single measureable statistic and Bamford (1970, 1972) found that the total fat reserves of individuals and the growth rate index were closely related to the rate of increase in the opossum populations. Batcheler *et al.* (1967) demonstrated that fat reserves influence the relative acceptance of poisoned baits.

Weight-length relationships

Standard statistical techniques were used to compare the means of body weights and total lengths for the 1+ - 6+ age classes in the moderate and high density populations (Tables 5 and 6). Data from the other age classes and the low density population were too few for valid comparisons,

although data for the low density population appear similar to those for the moderate density one. There were no obvious differences for older age classes in the high and moderate density populations compared with the 5+ and 6+ age classes of the same population.

TABLE 5. MEAN BODY WEIGHTS FOR OPOSSUMS IN THE 1+ - 6+ AGE CLASSES IN THE HIGH AND MODERATE DENSITY POPULATIONS, COPLAND VALLEY, 1978.

Age class	N	Body weight (kg) ± S.D.		Difference	t	Level of significance
		High	Moderate			
1+	24	0.91±.20	2.23±.28	0.40	2.92	.01
2+	30	1.83±.16	3.13±.44	0.84	3.85	.005
3+	25	2.29±.65	3.65±.51	0.51	2.53	.025
4+	22	3.14±.45	4.16±.49	0.82	4.38	.005
5+	16	3.38±.38	4.69±.48	1.36	7.27	.005
6+	11	3.47±.45	4.56±.25	1.09	3.27	.01

TABLE 6. MEAN TOTAL LENGTHS FOR OPOSSUMS IN THE 0+ - 6+ AGE CLASSES IN THE HIGH AND MODERATE DENSITY POPULATIONS, COPLAND VALLEY, 1978

Age class	N	Total length (cm) ± S.D.		Difference	t	Level of significance
		High	Moderate			
1+	24	70.6±3.4	75.0±3.6	4.4	2.63	.025
2+	30	75.3±6.0	81.2±3.5	3.9	4.84	.005
3+	25	82.0±3.6	85.0±3.3	3.0	2.11	.05
4+	22	82.4±2.0	86.6±3.3	4.2	3.74	.005
5+	16	83.3±3.2	88.0±2.3	4.7	2.35	.05
6+	11	82.3±4.4	90.3±0.4	8.0	2.48	.05

When the data for all adult opossums are pooled (Table 7) a valid comparison can be made between all the populations including the low density one. Significant differences exist for the mean adult body weights between the high (3.27 ± 0.57 kg) and moderate (3.58 ± 0.67 kg) density populations ($t=2.76$, $p<.01$) and the moderate and low (4.11 ± 1.09 kg) density populations ($t=2.18$, $p<.05$). The difference between the high and low density populations is highly significant ($t=6.40$, $p<.001$).

TABLE 7. MEAN ADULT BODY WEIGHTS FOR OPOSSUMS FROM THE HIGH, MODERATE AND LOW DENSITY POPULATIONS, COPLAND VALLEY, 1978.

Area	N	Adult body weight (kg) ± S.D.	Range
High	68	3.27 ± 0.57	1.58 - 4.52
Moderate	54	3.58 ± 0.67	2.31 - 5.20
Low	12	4.11 ± 1.09	2.47 - 6.40

The significant differences between both the moderate and low density populations and the high density population are expected in animals of genetically similar populations subjected to different nutrient regimens throughout their lives. A significant difference between the moderate and low density populations was not expected, for if these populations are increasing (as they were assumed to be) density differences between the areas should not give rise to limiting factors at any level (e.g. food resources, nest sites).

Standard weight equations for each population obtained from model I regressions of body weight and total length data, are similar to those of Bamford (1970) in expressing weight (W) as a cube of total length (L):

High density population $W = 0.00578\ L^{2.99841}$

Moderate density population $W = 0.00167\ L^{3.28151}$

Low density population $W = 0.00025\ L^{3.72416}$

The slopes of the regression lines (Snedecor & Cochran 1967) for the high (slope = 2.99841) and moderate (slope = 3.28151) density populations are significantly different ($t = 2.29$, $p<.025$). The diverging slopes suggest that animals from both populations are of similar body weight at or slightly before independence and that growth differences become more pronounced as the animals grow older. Although the slopes of the regression lines for the moderate (slope = 3.28151) and low (slope = 3.72416) density populations are significantly different ($t = 2.21$, $p<.05$), removal of the data set for the heaviest opossum in the low density population changes the exponent (i.e. slope) of the equation considerably and reduces the difference to non-significant proportions.

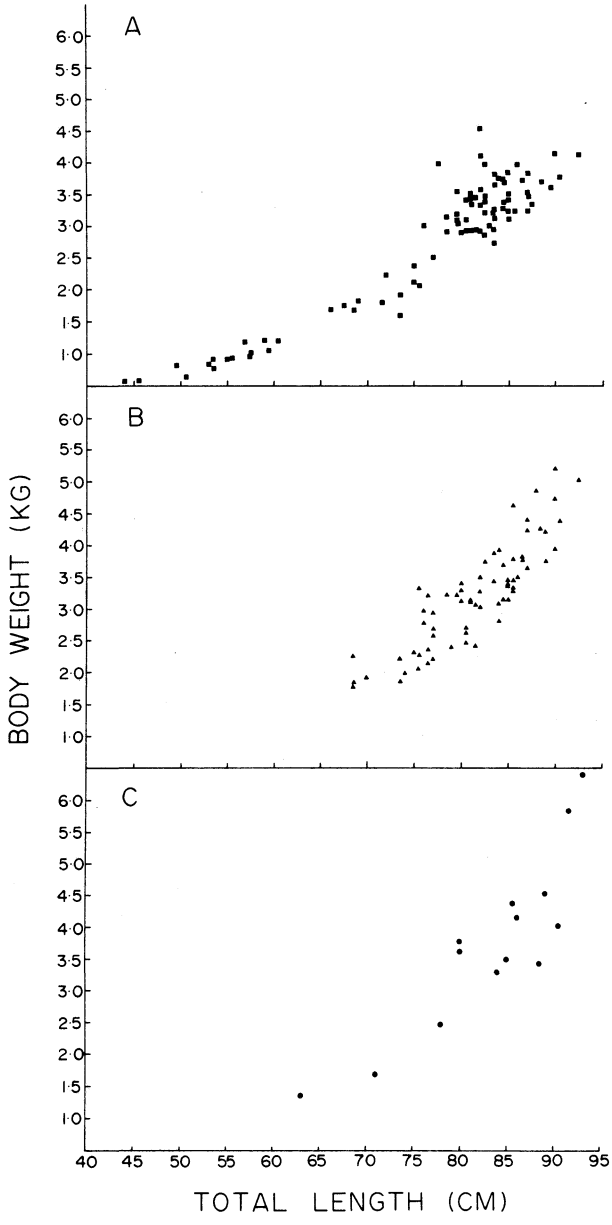

Fig. 3. Relationship between body weight and total length for opossums in high density (A), moderate density (B), low density (C) opossum populations in the Copland Valley.

Figures 3A and B show a marked difference in the variation of the weight-length relationship between the high and moderate density populations. This highly significant difference ($F_{1,160} = 18.2$, $p<.001$) is probably due to limiting food resources in the high density area suppressing natural variation.

Adult males (mean body wt = 3.46 ± 0.54 kg) were significantly heavier than adult females (2.99 ± 0.85 kg) in the high density population ($t = 2.20$, $p<.05$) but there was no significant difference between mean body weights of the sexes in both the moderate and low density populations (Table 8). This significant difference only in the well-established population indicates that males better utilise the limited food resources. Adult male opossums have larger home ranges than females (Crawley 1973, Jolly 1976) and this should increase their available food resources. Alternatively, since growth continues after sexual maturity the younger mean ages of the moderate and low density populations (2.4 and 2.8 years respectively) as compared with that of the high density population (3.8 years) could mean that these growth differences between the sexes have not reached significant levels yet.

TABLE 8. VARIATION IN BODY WEIGHT BETWEEN MALE AND FEMALE ADULT OPOSSUMS, COPLAND VALLEY, 1978.

Area	Body weight (kg) ± S.D.		t	Level of significance
	Male	Female		
High	3.46±0.54	2.99±0.85	2.20	.05
Moderate	3.65±0.77	3.45±0.52	1.10	n.s.
Low	4.41±1.36	3.82±0.74	0.93	n.s.

Within each population body weight did not increase significantly after the 4+ age class and total length did not increase significantly after the 3+ age class (Tables 5 and 6). Thus when linear growth ceases, increases in fat deposition occur. For opossums in the Orongorongo Valley (Wellington), Kean (1971) found that increase in length mostly stopped at 2 years and body weight did not increase significantly after 2.5 years. The greater ultimate size of males suggests that they continue to grow later than females. Most other stable or long-established opossum populations studied in New Zealand exhibit greater mean size for adult males (Gilmore 1966, Crawley 1973, Kean 1975).

These date support the hypothesis that greater growth is achieved in increasing opossum populations than in peak density populations. Both body weight and total length are consistently and significantly greater in each age class in the moderate density population and as the period of growth of the opossums is the same in both these populations the variation must be due to a differential growth rate. However,

growth data should be interpreted with caution as differential mortality of weaker animals increases the observed growth rate of the survivors (Caughley 1967). Since differential mortality is probably important in only the high density population, the apparent differences between this and the other populations may be even greater than indicated.

The short duration of this study precluded examination of seasonal body weight changes (Gilmore 1966, Bamford 1970). Calculations of standard weight from regression with total length, a skeletal measurement, further reduced variations due to gut contents or losses of body fluids (Klein 1964, Wood and Cowan 1968).

Condition

Although fat indices for estimating condition vary with season, age and sex, as well as with nutrition (Riney 1955, Caughley 1967, Bamford 1970), Bamford (1970) found a linear relationship between total fat reserves and a body weight index. An abdominal fat rating similar to that of Riney (1955) was used to estimate condition. Riney's (1955) system was reduced to a three-point rating since scoring young, rapidly growing animals with little or no fat reserves as zero, would unevenly bias the index and mask or exaggerate differences between populations.

There was a significant difference in mean abdominal fat reserves between the high and moderate density populations ($F_{1,160} = 28.2$, $p<.01$) (Table 9). The moderate and low density populations had identical, mean abdominal fat reserves ($F_{1,85} = 0.0$) (Table 9) and more than 70% of these opossums had abundant fat reserves. In extreme cases, numerous broad layers of fat lay along the mesenteries, around abdominal blood vessels and almost obscured the kidneys, ureters and female reproductive organs.

TABLE 9. ANALYSIS OF VARIANCE OF ABDOMINAL FAT RESERVES OF OPOSSUMS BETWEEN HIGH, MODERATE AND LOW DENSITY POPULATIONS, COPLAND VALLEY, 1978. *

Area	Abdominal fat rating			Mean	F value	Level of significance
	1	2	3			
High	12	39	38	2.29	28.2	.01
Moderate	-	16	57	2.78		
Low	-	3	11	2.78	0.0	n.s.

* Pouch young are omitted from this analysis.

These results agree with the findings of Caughley (1967) and Bamford (1970) in relating fat reserves to the eruptive state of the population: large fat reserves are characteristic of expanding populations where food is abundant while stable populations typically have diminished fat deposits and declining populations have even less fat reserves (Caughley 1967).

In attempting to apply Riney's (1955) kidney fat index to red deer, Batcheler and Clarke (1970) found that kidney weights varied seasonally. Kidney weight as a percentage of total body weight was examined as an estimate of food-related condition for each population (Table 10). Values are very similar for the high, moderate, and low density populations (0.33%, 0.29% and 0.28% respectively) but slightly higher than those reported by Gilmore (1966) and Voller (1969) (0.29% and 0.25% respectively). The higher values in this study are due to the inclusion of juveniles and sub-adults because kidneys are proportionately heavier in these age classes (0.53% in pouch young) (Gilmore 1966). Although the mean kidney weight for the moderate density population (9.16 g) is greater than that for the high density population (8.99 g), the total body weights show the same relationship to a far greater extent. This implies a pattern of negative heterogonic growth and confirms that use of kidney weight alone as an estimate of condition is limited.

TABLE 10. MEAN KIDNEY WEIGHTS EXPRESSED AS A PERCENTAGE OF THE TOTAL BODY WEIGHT FOR OPOSSUMS FROM THE COPLAND VALLEY, 1978.

Area	Mean kidney weight (% body wt.)	t	Level of significance
High	0.33 ± .028		
Moderate	0.29 ± .022	10.94	.001
Low	0.28 ± .018	1.60	n.s.

Damaged and torn ears often result from aggressive behaviour between males. A small number of males in the high density population did have damaged ears but such signs of social stress were not seen in the other two populations. None of the animals examined was tuberculous or showed symptoms of other diseases. External parasites on the rump and around the base of the tail were noted on only a few of the animals from the high density population. These parasites, which caused bare or thin patches in the fur, were not identified but species of ticks and mites (O. Acarina) have been recorded on opossums in New Zealand (Womersley 1956, Pracy and Kean, 1968).

Within the Copland Valley there are obvious density related differences between the populations in terms of the growth rate, asymptotic size, and condition of the opossums. Body weights and total lengths for all age classes are significantly greater in the moderate density population compared to the high density one, and males were significantly heavier than females in the high density population only. As well as a significant difference in the abdominal fat deposits between these two populations, other indices of condition such as signs of fighting and the incidence of parasites verified

that opossums from the high density area in the lower Copland Valley were in poorer condition. These parameters are unlikely to be static and almost certainly change in accordance with the populations' dynamics, reflecting their relationships with the habitat.

TABLE 11. SUMMARY OF THE OPOSSUM POPULATION CHARACTERISTICS' IN THE THREE AREAS STUDIED.

	Lower Copland Valley	Mid-Copland Valley	Upper Copland Valley
Relative population density	high	moderate	low
Population trend	stable or declining	increasing	increasing
Age structure	predominantly older	predominantly young	predominantly young
Average age (years)	3.8	2.4	2.8
Sex ratio	excess females	excess males	parity
Age at sexual maturity (years)	3+	2+	2+
Spring breeding	no	yes	yes
Mean adult body wt. (kg)	3.27	3.58	4.11
Relative growth rate	slow	rapid	rapid
Fat-related condition	poor	good	excellent
Ectoparasites and/or signs of fighting	yes	no	no

CONCLUSIONS

The information summarised in Table 11 confirms the hypothesis that populations at different stages of eruptive fluctuations exhibit characteristic population dynamics features and growth and condition patterns that reflect their relationships with the habitat. It can be concluded therefore that the opossum populations in the Copland Valley represent various stages of an eruptive fluctuation sequence from the stable or declining, relatively poor condition population in the lower Copland Valley, through the increasing, good condition population in the mid-Copland Valley, to the pioneer population in the upper Copland Valley which is in very good condition.

ACKNOWLEDGEMENTS

This work was part of a B.Sc.(Hons) project. I thank Dr M.C. Crawley for his advice and criticism of the manuscript, Mr B. Warburton and Mr P. de Haan for their assistance with the field work, Dr J.D. Coleman and Mr C.J. Peckelharing for valuable discussion of the initial results, and the N.Z.F.S. for providing financial support. I also thank Mr G. Fenwick and Mr R. Stephenson for their helpful criticism and patience!

LITERATURE CITED

BAMFORD, J. 1970. Estimating fat reserves in the brush-tailed possum, *Trichosurus vulpecula* Kerr (Marsupialia: Phalangeridae). *Australian Journal of Zoology 18:* 415-25.

BAMFORD, J. 1972. The dynamics of possum (*Trichosurus vulpecula* Kerr) populations controlled by aerial poisoning. Unpublished Ph.D. thesis, University of Canterbury, New Zealand. 158 pp.

BATCHELER, C.L., DARWIN, J.H. and PRACY, L.T. 1967. Estimation of opossum (*Trichosurus vulpecula*) populations and results of poisoning trials from trapping data. *New Zealand Journal of Science 10:* 97-114.

BATCHELER, C.L. and CLARKE, C.M.H. 1970. Note on kidney weights and the kidney fat index. *New Zealand Journal of Science 13:* 663-68.

BOERSMA, A. 1974. Opossums in the Hotitika River catchment. *New Zealand Journal of Forestry Science 4:* 64-75.

BRODY, S. 1945. Bioenergetics and Growth. Reinhold Publishing Company, New York. 1023 pp.

CATT, D.C. 1975. Growth, reproduction, and mortality in Bennett's wallaby (*Macropus rufogriseus fructicus*) in South Canterbury, New Zealand. Unpublished M.Sc. thesis, University of Canterbury, New Zealand. 138 pp.

CAUGHLEY, G. 1967. Growth, stabilisation and decline of New Zealand populations of the Himalayan thar (*Hemitragus jemlahicus*). Unpublished Ph.D. thesis, University of Canterbury, New Zealand. 137 pp.

CAUGHLEY, G. 1970. Eruption of ungulate populations, with emphasis on Himalayan thar in New Zealand. *Ecology 51:* 53-72.

CAUGHLEY, G. and BIRCH, L.C. 1971. Rate of increase. *Journal of Wildlife Management 35:* 658-63.

CAUGHLEY, G. and KEAN, R.I. 1964. Sex ratios in marsupial pouch young. *Nature 204:* 491.

COLE, L.C. 1954. The population consequences of life history phenomena. *The Quarterly Review of Biology 29:* 103-37.

COLEMAN, J.D. 1976. Pararaki Possums. Unpublished New Zealand Forest Service File Note. 6 pp.

CRAWLEY, M.C. 1973. A live-trapping study of Australian brush-tailed possums, *Trichosurus vulpecula* (Kerr), in the Orongorongo Valley, Wellington, New Zealand. *Australian Journal of Zoology 21:* 75-90.

DUNNET, G.M. 1956. A live-trapping study of the brush-tailed possum *Trichosurus vulpecula* Kerr (Marsupialia). *C.S.I.R.O. Wildlife Research 1:* 1-18.

DUNNET, G.M. 1964. A field study of local populations of the brush-tailed possum *Trichosurus vulpecula* in eastern Australia. *Proceedings of the Zoological Society, London 157:* 665-95.

FARMER, A.P. 1973. Assessment of animal damage in exotic forests of the central North Island. *New Zealand Forest Research Institute, Symposium No. 14:* 32-36.

FRASER, K.W. 1978. The status of opossum populations (*Trichosurus vulpecula* Kerr) in the Copland Valley, Westland. Unpublished B.Sc.(Hons) project, University of Canterbury, New Zealand. 79 pp.

GILMORE, D.P. 1966. Studies on the biology of *Trichosurus vulpecula* Kerr. Unpublished Ph.D. thesis, University of Canterbury, New Zealand. 300pp.

HARVIE, A.E. 1973. Diet of the opossum (*Trichosurus vulpecula* Kerr) on farmland northeast of Waverley, New Zealand. *Proceedings of the New Zealand Ecological Society 20:* 48-52.

HOLLOWAY, J.T. 1959. Noxious-animal problems of the South Island alpine watersheds. *New Zealand Science Review 17:* 21-28.

HOLLOWAY, J.T. 1970. Introduced animals and the protection forests. Pp.11-17 *In:* Poole, A.L. (Ed.) *Wild Animals of New Zealand.* A.H. & A.W. Reed, Wellington. 151 pp.

HOLLOWAY, J.T. 1973. The status quo in animal control and management: a research assessment. *New Zealand Forest Research Institute, Symposium No. 14:* 125-30.

JOLLY, J.N. 1976. Movements, habitat use and social behaviour of the opossum, *Trichosurus vulpecula*, in a pastoral habitat. Unpublished M.Sc. thesis, University of Canterbury, New Zealand. 117 pp.

KEAN, R.I. 1967. Behaviour and territorialism in *Trichosurus vulpecula* in New Zealand. *Proceedings of the New Zealand Ecological Society 14:* 71-78.

KEAN, R.I. 1971. Selection for melanism and for low reproductive rate in *Trichosurus vulpecula* (Marsupialia). *Proceedings of the New Zealand Ecological Society 18:* 42-47.

KEAN, R.I. 1975. Growth of opossums (*Trichosurus vulpecula*) in the Orongorongo Valley, Wellington, New Zealand, 1953-61. *New Zealand Journal of Zoology 2:* 435-44.

KEAN, R.I. and PRACY, L.T. 1949. Effects of the Australian opossum on indigenous vegetation in New Zealand. *Proceedings of the Seventh Pacific Science Congress 4:* 696-715.

KENDEIGH, S.C. 1961. Animal Ecology, Prentice-Hall Inc. Englewood Cliffs, N.J. 474 pp.

KLEIN, D.R. 1964. Range-related differences in growth of deer reflected in skeletal ratios. *Journal of Mammology 45:* 226-35.

MIERS, K.H. 1973. Animals in forests: present policy and position in animal control and management. *New Zealand Forest Research Institute, Symposium No. 14:* 89-96.

NEW ZEALAND METEOROLOGICAL SERVICE. 1973. Rainfall Percentiles. Government Printer, Wellington, N.Z. 98pp.

NEW ZEALAND SOIL BUREAU. 1950. Soils and agriculture of Westland. *New Zealand Soil Bureau Bulletin 2.* 24 pp.

NEW ZEALAND SOIL BUREAU. 1968. Soils of New Zealand, Part 1. *New Zealand Soil Bureau Bulletin 26(1).* 142 pp.

PARKES, A.S. 1926. The mammalian sex ratio. *Biological Reviews 2:*1-51.

PECKELHARING, C.J. 1970. Cementum deposition as an age indicator in the brush-tailed possum, *Trichosurus vulpecula* Kerr (Marsupialia). *Australian Journal of Zoology 18:* 71-76.

PRACY, L.T. 1962. Introduction and liberation of the opossum (*Trichosurus vulpecula*) into New Zealand. *New Zealand Forest Service Information Series No. 45.* 28 pp.

PRACY, L.T. and KEAN, R.I. 1968. Tapeworms found in opossums. *New Zealand Journal of Agriculture 117:* 21.

RINEY, T. 1955. Evaluating condition of free-ranging red deer (*Cervus elaphus*), with special reference to New Zealand. *New Zealand Journal of Science and Technology 36B:* 429-63.

SNEDECOR, G.W. and COCHRAN, W.G. 1967. Statistical Methods. (6th ed.) Iowa State University Press, Iowa, U.S.A. 593 pp.

TYNDALE-BISCOE, C.H. 1955. Observations on the reproduction and ecology of the brush-tailed possum, *Trichosurus vulpecula* Kerr (Marsupialia), in New Zealand. *Australian Journal of Zoology 3:* 162-84.

VOLLER, R. 1969. Some statistics from a population of brush-tailed opossums sampled within the breeding season. Unpublished M.Sc. project, University of Canterbury, New Zealand. 22 pp.

VON BERTALANFFY, L. 1934. A quantitative theory of organic growth (inquiries on growth Laws II). *Human Biology 10:* 181-213.

WARBURTON, B. 1977. Ecology of the Australian brush-tailed possum (*Trichosurus vulpecula* Kerr) in an exotic forest. Unpublished M.Sc. thesis, University of Canterbury, New Zealand. 117 pp.

WARDLE, P. 1977. Plant communities of Westland National Park (New Zealand) and neighbouring lowland and coastal areas. *New Zealand Journal of Botany 15:* 323-98.

WODZICKI, K.A. 1950. Introduced mammals of New Zealand. *Department of Scientific and Industrial Research Bulletin No. 98.* 250 pp.

WOMERSLEY, H. 1956. On some new Acarina - Megostigmata from Australia, New Zealand and New Guinea. *Journal of the Linnean Society of London, Zoology 288:* 505-99.

WOOD, A.J. and COWAN, I. McT. 1968. Post natal growth. Pp.106-113. *In:*Golley, F.B. and Buechner, H.K. (Eds.) *A Practical Guide to the Study of the Productivity of Large Herbivores.* IBP Handbook No. 7. Blackwell Scientific Publications, Oxford. 308 pp.